Heavy Quarks in Strongly Coupled Plasmas with Chemical Potential*

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Introduction

In heavy ion collisions at RHIC and LHC, it is found that the produced quark–gluon plasma (QGP) is strongly coupled. We apply gauge/gravity duality [1] to study heavy quarks in strongly coupled non-Abelian plasmas. To approximate a dual description of QCD, we study non-conformal gauge theories by explicitly breaking the conformal invariance of the prototype AdS/CFT correspondence. As there is freedom in the way this breaking can be introduced, we study large classes of asymptotically AdS spacetimes, and try to uncover possible universal behavior common to all dual theories. Furthermore, to learn about the phase structure of strongly coupled gauge theories, and ultimately about parts of the QCD phase diagram, we include a chemical potential into our studies. Experimentally, this will be addressed *e. g.* in future FAIR experiments.

Specifically, we have computed the screening distance, the free energy, and a derived running coupling of heavy $Q\bar{Q}$ pairs moving in the strongly coupled plasmas described above. The methods used and results from studies in conformal theories are reviewed *e. g.* in [2].

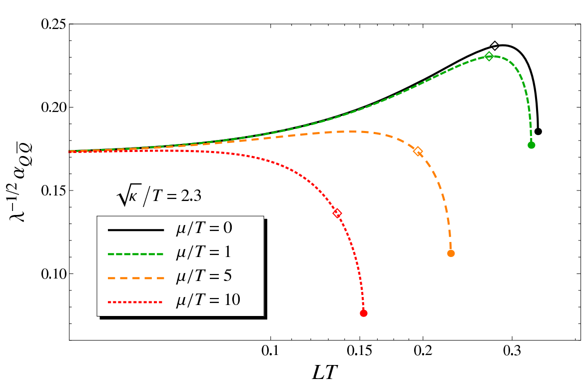

Figure 1: Running coupling $\alpha_{Q\bar{Q}}(L)$ in a non-conformal plasma at temperature T for varying values of the chemical potential μ. $\sqrt{\lambda}$ is a constant. At the endpoints of the curves, screening of the $Q\bar{Q}$ interaction due to the plasma takes over.

Free Energy and Running Coupling

We compute the free energy $F(L)$ of a bound $Q\bar{Q}$ pair with interquark distance L immersed in the medium. To get a handle on the effect of non-conformality on the interaction in more detail, we study the running coupling defined via the derivative of the free energy,

$$\alpha_{Q\bar{Q}}(L) \equiv \frac{3}{4} L^2 \frac{\mathrm{d}F(L)}{\mathrm{d}L}\,.$$

It is shown in Fig. 1. For small distances L, conformality is restored with $\alpha_{Q\bar{Q}}$ becoming constant, while for larger distances, both non-conformality and thermal effects lead to deviations of $\alpha_{Q\bar{Q}}$ from being constant. We have found a universal increase in $\alpha_{Q\bar{Q}}$ above the UV value due to non-conformality, both at vanishing and non-zero chemical potential μ. At still larger distances, thermal effects decrease $\alpha_{Q\bar{Q}}$. This pattern is also seen in QCD lattice data [3].

We have investigated the dependence of characteristic scales on temperature and chemical potential (*i. a.* the thermal drop-off scale L_{th} and the scale L_{max} where $\alpha_{Q\bar{Q}}$ assumes its maximum). At vanishing chemical potential, we have found that to leading order in our models with strong deformation away from conformality, $L_{\mathrm{max}} \sim \frac{c}{T^2}$, where c is the deformation parameter. This appears to be only weakly altered for $\mu > 0$. Generally, we have found that the effect of the chemical potential is relatively weak: also L_{th} varies more strongly under changes in T than in μ.

Comparing the free energy for non-zero μ to lattice data [4] where these are available, *i. e.* for $\mu/T \ll 1$, we find qualitative differences in the effect of the chemical potential that require further analysis. For our further studies, a very interesting outlook is to refine the comparison to lattice data to better characterize the commonalities and differences of holographic models for strongly coupled plasma and the QGP and to learn more about the nature of chemical potentials in holography.

Parts of these results were presented in [5], a more detailed account will be published elsewhere.

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